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Inertial Navigation System Simulator: Behavioral Specification

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Review and Approval

This report has been reviewed and is approved for publication.

FOR THE COMMANDER

Charles J. Ryan, Major, USAF
SEI Joint Program Office

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Inertial Navigation System Simulator Behavioral Specification

Abstract: The Real-Time Embedded Systems Testbed (REST) Project at the Software Engineering Institute is specifying and developing a representative real-time application. This document augments an original set of specifications written by a Navy affiliate. The purpose of this behavioral specification is to clarify and augment the original.

1. Introduction

The Inertial Navigation System (INS) Simulator system [Meyers 88a] consists of the INS computer, the external computer (EC), the INS simulator program [Meyers 88b], the external computer program [Meyers 88c], and an operator interface to each.

This document specifies the INS simulator program in terms of its external interfaces and its dynamic behavior. The purpose is to clarify and supplement the functional specification [Meyers 88b].

The document contains five chapters:

1. **Introduction**
2. **Input/Output Interfaces**: Specifies the external interfaces of the INS simulator computer in terms of the data structures that are transferred and the layout of the information presented to the operator (i.e., a static view).
3. **External Behavior**: Describes the externally visible behavior of the INS simulator program in terms of the responses to specified inputs and the conditions for generating particular outputs (i.e., a dynamic view).
4. **Internal Behavior**: Describes those aspects of the behavior of the INS simulator program that are not directly visible (e.g. motion simulation calculations).
5. **Initialization, Control, and Termination**: Describes the overall process of initializing, controlling, and terminating the INS simulator program.

Two appendices are included:

- **Timing Constraints**: Contains a summary of timing constraints that were extracted from the functional specification [Meyers 88b].
- **Communications Link Statecharts**: Contains a collection of state transition diagrams (statecharts) that define in detail the required behavior of the communications link.

2. Input/Output Interfaces

This chapter specifies the external interfaces of the INS simulator computer in terms of the data structures that are transferred and the layout of the information presented to the operator. This is a static view of the external interfaces; the externally visible, dynamic behavior of the INS simulator program is specified in the next chapter.

Figure 2-1 shows a high-level view of the external interfaces of the INS simulator computer. The actual physical interfaces are highly implementation dependent and will not be specified here. Each of the following sections will describe one of these interfaces: the communications link between the two computers, interface to the keyboard, interface to the screen, and interface to a disk file.

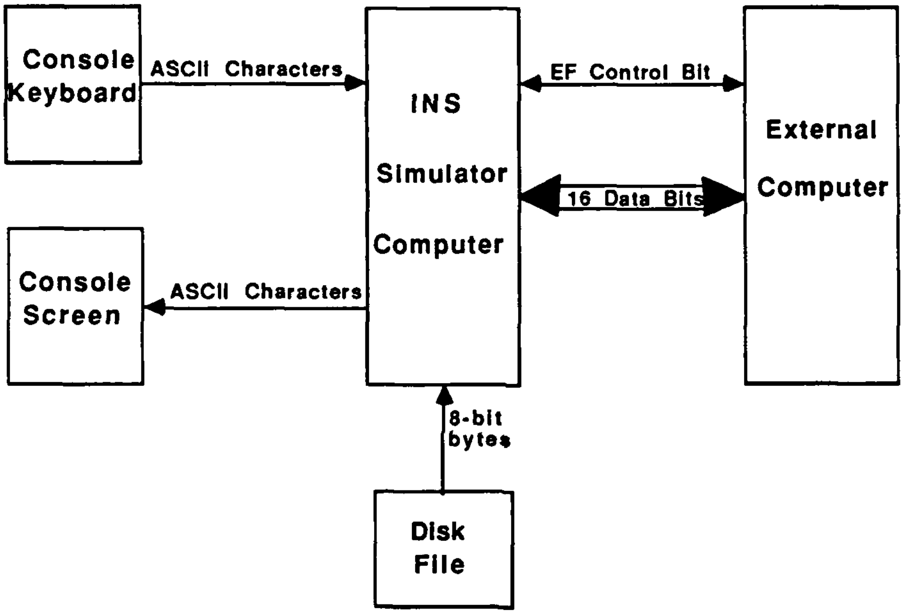

Figure 2-1: Inertial Navigation System Computer Interfaces

2.1. Communications Link

The communications link is used to transfer messages between the INS simulator computer and the external computer system.

2.1.1. Logical Interface

As shown in Figure 2-1, the logical interface to or from the external computer consists of a stream of 17-bit elements, each element consisting of a 16-bit data word and an associated external function (EF) control bit. If the EF bit is high, the data word is interpreted as an external function code; otherwise it is interpreted as a normal message word.

2.1.2. External Function (EF) Codes

The EF codes are used to control the communications protocol and to delimit messages. The code identifiers and their functions are listed in Table 2-1. The actual bit patterns are specified in [NAVSEA 82]. Note that not all the EF codes defined in [NAVSEA 82] are used in the INS simulator application.

Code	Function
ATTN1	Indicate a time-out condition
ATTN2	Enable communications
ATTN4	Disable communications (sent by EC* only)
SOTM	Start of test message
SOM**	Start of message
RTR	Ready to receive
NRTR	Not ready to receive (sent by EC* only)
EOM	End of message
ACK	Acknowledge (i.e., received a valid message)
NAK	Not-Acknowledge (i.e., received an incomplete or invalid message)

* External Computer System
** Start of Message

Table 2-1: External Function (EF) Codes

2.1.3. Message Types and Formats

The full range of message types and formats is defined in [NAVSEA 82]. The INS simulator application uses only some of these message types. The message types that may be transmitted to the EC are listed in Table 2-2. The message types that may be received from the EC are listed in Table 2-3. The contents, but not the detailed formats, of these messages are depicted in Tables 2-4, 2-5, 2-6, 2-7, and 2-8. Each message begins with a 2-word header block which specifies the message type and the word count.

Message Type	Message Contents
Test Message	Contains a fixed pattern to allow checking of communications
Time and Status Data Message	Contains fields for the time-of-day and various status codes
Attitude Data Periodic Message	Contains various fields of numerical data pertaining to the (simulated) ship motion
Navigation Data Periodic Message	Contains fields of numerical data pertaining to the (simulated) ship motion

Table 2-2: Messages to External Computer (EC)

Message Type	Message Contents
Test Message	Contains a fixed pattern to allow checking of communications
Select Data Message	Contains fields to select/deselect the periodic messages that may be sent from the INS

Table 2-3: Messages from External Computer (EC)

Message Field	Word Count
Message Header	2 words
Source Identification	1 word
Spare	1 word
Test Word TW1	2 words
Test Word TW0	2 words
---------------------	------------
Total	8 words

Table 2-4: Test Message

Message Field	Word Count
Message Header	2 words
Status	2 words
GMT*	2 words
Test Word TW1	2 words
Test Word TW0	2 words
---------------------	------------
Total	10 words

* Greenwich Mean Time

Table 2-5: Time and Status Data Message

Message Field	Word Count
Message Header	2 words
Data Selection	1 word
Spare	1 word
Test Word TW1	2 words
Test Word TW0	2 words
---------------------	------------
Total	8 words

Table 2-6: Select Data Message

Message Field	Word Count
Message Header	2 words
Ownship Heading	1 word
Ownship Pitch	1 word
Ownship Roll	1 word
Ownship Heading Rate	1 word
Ownship Pitch Rate	1 word
Ownship Roll Rate	1 word
GMT*	2 words
East Component of Ownship Velocity	1 word
North Component of Ownship Velocity	1 word
Vertical Component of Ownship Velocity	1 word
Ownship Speed	1 word
Test Word TW1	2 words
Test Word TW0	2 words
Total	18 words

* Greenwich Mean Time

Table 2-7: Attitude Data Periodic Message

Message Field	Word Count
Message Header	2 words
Latitude	2 words
Longitude	2 words
East Component of Ownship Velocity	1 word
North Component of Ownship Velocity	1 word
East Component of Ocean Current	1 word
North Component of Ocean Current	1 word
Ownship Speed	1 word
EM* Log Calibration Constant	1 word
Ownship Heading	1 word
Ownship Pitch	1 word
Ownship Roll	1 word
Radial Error Estimate	1 word
Time of Gyro Reset	2 words
GMT**	2 words
SOM*** GMT	2 words
Integral of Velocity North	2 words
Integral of Velocity East	2 words
Test Word TW1	2 words
Test Word TW0	2 words
Total	30 words

* Electro-Magnetic
** Greenwich Mean Time
*** Start of Message

Table 2-8: Navigation Data Periodic Message

2.2. Console Keyboard

The console keyboard is used to allow the operator to enter various commands.

2.2.1. Logical Interface

As shown in Figure 2-1, the logical interface to the console keyboard consists of a stream of ASCII characters.

The following characters are accepted from the keyboard:

> **a .. z, A .. Z, 0 .. 9, =, +, -, ., horizontal tab, space, backspace, delete, escape, carriage return**

All other characters are ignored.

2.2.2. Command Syntax

The functions of the control characters are shown in Table 2-9.

Character	Function
ESC	A special signal to the alert processing function (see Section 3.3.2)
HT	Equivalent to a space
BS	Used to delete the previous character
DEL	Used to delete the command string
CR	Signals the end of a command string

Table 2-9: Keyboard Control Characters

The non-control characters (including the space character) are used to construct operator commands as specified by the syntax equations in Tables 2-10 and 2-11.

```
SET <parameter-name> = <parameter-value>

SHOW {<parameter-name> | *}

FAULT <variable-name> = <fault-value>

TURN TO {PORT | STARBOARD} AT <turn-rate> UNTIL COURSE <new-course>

{INCREASE | DECREASE} SPEED TO <speed-value> IN <time-period>

RESET GYRO

ENTER

USE FILE  <file-name>

SELECT {SEASTATE | SCENARIO} <n>

BEGIN

PAUSE

EXIT

CLEAR
```

Notes:

1. <parameter-name> is any input parameter to the motion simulation and <parameter-value> is any legal value for the parameter.
2. <variable-name> is any data variable in an output message to the EC and <fault-value> is any value which can occupy the designated storage allotment for that variable in the output message.
3. <speed-value>/<time-period> must be less than 800 knots per hour.
4. <parameter-name> and range of <parameter-value> must be verified after issuing the SET command (actual value of parameter is not changed until ENTER command is issued).
5. All numeric values are expressed in fixed point notation which accepts signed and unsigned integers and real numbers.
6. The note after Table 3-3 distinguishes between commands that are specified in [Meyers 88b] and those that have been added by the designers.

Table 2-10: Operator Command Syntax, Part 1

<parameter-name>	UNITS	MIN*	MAX*
HEAVE_AMP	feet	0	14
HEAVE_FREQ	radians/sec	0	0.5
HEAVE_PHASE	radians	0	360
LAC_A	feet	-250	250
LAC_B	feet	-25	25
LAC_C	feet	-25	25
LATITUDE	degrees	-90	90
LIST	degrees	-2	2
LONGITUDE	degrees	-180	180
OCEAN_E	knots	-12	12
OCEAN_N	knots	-12	12
PITCH_AMP	degrees	0	5
PITCH_FREQ	radians/sec	0	0.5
PITCH_PHASE	radians	0	360
ROLL_AMP	degrees	0	40
ROLL_FREQ	radians/sec	0	0.5
ROLL_PHASE	radians	0	2*Pi
SHIP_COURSE	degrees	0	360
SHIP_SPEED	knots	0	40
SURGE_AMP	feet	0	15
SURGE_FREQ	radians/sec	0	0.5
SURGE_PHASE	radians	0	2*PI
SWAY_AMP	feet	0	20
SWAY_FREQ	radians/sec	0	0.5
SWAY_PHASE	radians	0	2*PI
TRIM	degrees	-2	2
YAW_AMP	feet	0	5
YAW_FREQ	radians/sec	0	0.5
YAW_PHASE	radians	0	2*PI
<turn-rate>	degrees/sec	0	2
<new-course>	degrees	0	360
<speed-value>	knots	0	40
<time-period>	minutes	0	120
<file-name>	alphanumeric	1	80[1]
<n>	integer	1	15

Table 2-11: Operator Command Syntax, Part 2

[1] File specifications should not exceed length of command line, which is 80 characters.

2.3. Console Screen

The *console screen* is used to display some system status indicators and numerical quantities pertaining to the simulated motion of the ship.

2.3.1. Logical Interface

As shown in Figure 2-1, the logical interface to the console screen consists of a stream of ASCII characters. The console screen is assumed to display at least 24 lines of 80 characters. The sequences of control characters required to position the cursor are implementation-dependent and are not described here.

2.3.2. Screen Layout

The screen is divided into four windows as shown in Figure 2-2. The detailed layout of the the screen is shown in Figure 2-3. Note that the command window, alert window, and the system status window are allocated two lines, but they actually consist of one line of information and a blank line for window separation.

	# Lines
Periodic Display Window	18
Command Window	2
Alert Window	2
System Status Window	2

Figure 2-2: Screen Windows

2.4. Disk File

The USE FILE command can accept a disk file name from the operator for input of a command script.

```
Latitude:   xxx.xx    North                                         GMT:  xx:xx:xx
Longitude:  xxx xx.xx East                                          TGR:  xx:xx:xx

                                                    Speed:      xx   knots
Course:     xxx.xx    deg                           Rate: ∓  xxx.xx  deg/second
Heading:    xxx.xx    deg                           Rate: ∓  xxx.xx  deg/second
Roll: ∓      xx.xx    deg                           Rate: ∓  xxx.xx  deg/second
Pitch: ∓     xx.xx    deg                           Rate: ∓  xxx.xx  deg/second
Yaw: ∓       xx.xx    deg

Surge:∓        xx.xx  feet    Sway: ∓  xx.xx  feet    Heave: ∓  xx.xx   feet
List:  ∓       xx.xx  deg     Trim: ∓  xx.xx  deg
Ocean(East):   xx.xx  knots       Ocean (North): xx.xx  knots

Vel  East:      xx.xx  knots    Cumulative: ∓  xxxxxx.x  feet
Vel  North:     xx.xx  knots    Cumulative: ∓  xxxxxx.x  feet
Vel  Vert:      xx.xx  knots
--------------------------------------------------------------------------------
INS>
--------------------------------------------------------------------------------
EC  Communications  UP                                            xxxxxx
--------------------------------------------------------------------------------
                                                           EC Status: UP
```

Figure 2-3: Detailed Screen Layout

2.4.1. Logical Interface

The logical interface between the disk file and INS consists of a stream of character strings, each terminated with a <CR>. The strings are composed of operator commands as defined in the syntax equations of Table 2-10 and Table 2-11.

3. External Behavior

This chapter describes the externally visible behavior of the INS simulator program, i.e., the responses to specified inputs and the conditions for generating particular outputs. The interfaces of concern are:

- interface with the external computer (system communications link)
- interface with the operator (keyboard and screen)
- interface with a disk file (command script execution)

3.1. Communications Link

As stated in [Meyers 88b], the communications link between the INS simulator computer and the external computer system must conform to the protocol specified in [NAVSEA 82]. The purpose of this section (and Appendix B) is to give a condensed version of the detailed information in [NAVSEA 82] and in [Meyers 88b].

Communications with the external computer can be in one of three states: disabled, enabling, or enabled. In each of these states, the INS sends and receives data while bound to a specific protocol (i.e., sequence of external function codes and data words). The INS can be viewed as a server to the external computer; that is, the external computer determines INS behavior and can cause preemption of INS message activity. The external computer initiates the enabling and disabling of the INS communications link, directs that certain data be sent or not sent, and periodically requests that the INS respond to test messages.
Sending a successful message consists of an exchange that includes a block of data words, preceded and followed by a pair of EF codes, as detailed in Table 3-1.

---

1. The initiator of a message sends a start-of-message (SOM).
2. The recipient, if ready, responds with a ready-to-receive (RTR) signal.
3. The initiator sends the data block, followed by an end-of-message (EOM) signal.
4. If no errors are detected, the recipient responds with an acknowledge (ACK).

Table 3-1: Normal Message Protocol

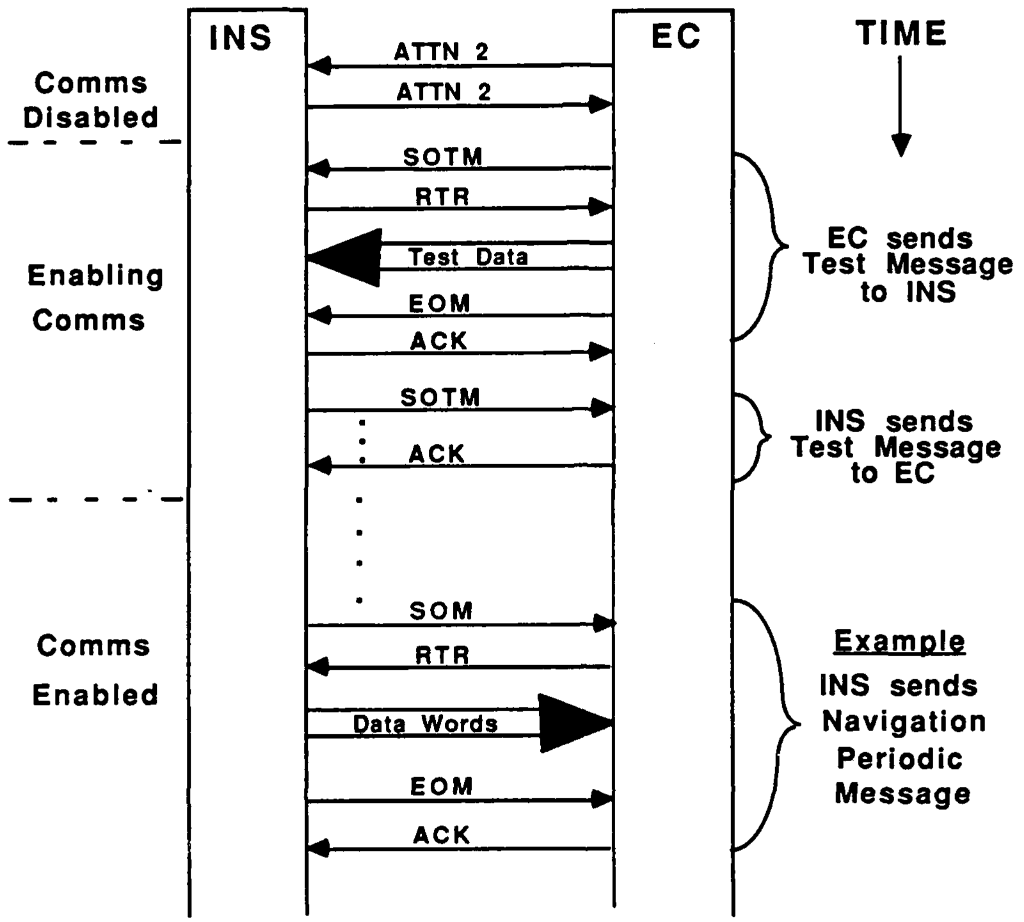

Figure 3-1: Communications Protocol: Summary

Figure 3-1 depicts the overall behavior of the communications link in the ideal case with no transmission errors. The communications link is initially in the disabled state. The external computer initiates the communications protocol with an ATTN2 EF; the INS responds with an ATTN2; and the system enters the enabling state. In the enabling state, the EC sends a test message, and the INS responds with a test message. After the successful exchange of these messages, the system enters the enabled state. In the enabled state, the INS computer accepts and sends messages as dictated by the functional requirements specified in [Meyers 88b] and summarized in Table 3-2. Note that in the case of a conflict, sending an attitude periodic data message takes precedence over sending a *navigation periodic* data message.

Message Type	Conditions
Time and Status Data Message	Sent immediately upon entry to the enabled state, and in response to a select data message from the EC*.
Test Message	Sent in response to a test message from the EC.
Attitude Periodic Message	Sent once every 61.44 milliseconds (approximately 16 Hz. frequency), if enabled by a previous select data message from the EC.
Navigation Periodic Message	Sent once every 983.04 seconds (approximately 1 Hz. frequency), if enabled by a previous select data message from the EC.

* External Computer

Table 3-2: Conditions for Generating Messages from INS

The idealized scenario of Figure 3-1 can be disrupted by a variety of events (e.g., intended recipient not ready, erroneous message, time-out waiting for a response). The full behavior of the communications link is defined in Appendix B.

Command	Effect
SELECT SEASTATE	Use the specified set of ship's attitude (ex: rotational amplitude, frequency) parameters for the motion simulation.
SELECT SCENARIO	Use the specified set of ship's navigation (ex: position, velocity) parameters for the motion simulation.
BEGIN	Start (or restart) the motion simulation.
SET PARAMETER	Save the new value of the specified parameter, to be used upon the next ENTER command.
SHOW PARAMETER	Display the value of the specified simulation parameter.
SHOW *	Display the values of all simulation parameters, usurping the periodic display window of the screen and disabling the normal periodic update of this window.
CLEAR	Erase the periodic display window of the screen, rewrite the fixed legends, and re-enable the normal periodic update of this window.
FAULT	Save the specified fault value of the specified variable; upon the next ENTER command, use that value to inject a fault into the next output data message, in place of its true value.
ENTER	Actually make the changes to the simulation parameters as specified in most recently issued SET PARAMETER and FAULT commands (i.e., issued since the last ENTER command).
COURSE	Use the new course parameters for the motion simulation.
SPEED TO	Use the new speed parameters for the motion simulation.
RESET GYRO	Set the Time of Gyro Reset to the current system time.
USE FILE	Open the specified file for use of INS Operator Commands. The input is in the form of a list of syntax equations defined in Tables 2-10 and 2-11.
PAUSE	Temporarily freeze the simulation (it may be restarted with the BEGIN command).
EXIT	Terminate the simulation program.

Table 3-3: Operator Commands

Note: The following commands are specified explicitly in [Meyers 88b]: SET PARAMETER, SHOW PARAMETER, COURSE, SPEED, ENTER, FAULT, and RESET GYRO.

The following commands are specified implicitly in [Meyers 88b]: SELECT SEASTATE and SELECT SCENARIO.

The following commands have been invented to provide needed functionality: BEGIN, PAUSE, EXIT, SHOW *, CLEAR, and USE FILE.[2]

[2][Meyers 88b] intended the USE FILE to be for data extraction (DX) rather than its current function.

3.2. Console Keyboard

The effect of each of the operator commands is described in Table 3-3.

3.3. Console Screen

The behavior of each window is defined separately.

3.3.1. Command Window

The command line is initially blank. As the operator types a command, the individual (printable) characters are echoed in the command line. If the operator uses the backspace (BS) and delete (DEL) characters to edit the command string, changes are reflected in the command line. The operator indicates the end of a command by typing a carriage-return (CR) character. This CR is not echoed directly; instead a "!" character is appended when a command has been executed successfully, or a "?" character is appended when a command has been found to be invalid.

When a SHOW PARAMETER command is entered, the value of the specified parameter is displayed in the remainder of the command line, in the following format:

SHOW PARAMETER <parameter-name> = <parameter-value> <unit-of-measure> !

where <parameter-name> is as specified in Section 2.2.2,
<parameter-value> is in the appropriate numeric form, and
<unit-of-measure> is as specified in Section 2.2.2.

A command remains on display until the first character of the next command is typed. Thus, the command line displays one of the following:

1. a blank line
2. an incomplete command string
3. an apparently complete command that has not yet been terminated with a CR
4. a complete command with an indication of whether it has been accepted
5. a SHOW PARAMETER command, followed by the value of the specified parameter

3.3.2. Alert Window

The alert line is blank at program initiation. When any of the events listed in Table 3-4 occurs, an alert will be issued (see [Meyers 88b]). If there is no alert currently displayed, the new alert is displayed; otherwise, the new alert is added to a list of pending (capacity of the list is 50 alerts). Additionally, the audible alarm will sound for 2 seconds when an alert is issued.

When the operator types an escape (ESC) character, the currently displayed alert (if any) is erased, and the highest priority pending alert (if any) is removed from the list of pending alerts and displayed.

Thus, the alert line is either blank, or it contains the following:

- the alert text string
- the time at which the alert was issued (i.e., detected)
- the number of pending alerts (blank if zero)

FAULT CHANGES COMPLETED
INVALID MESSAGE TYPE IN MESSAGE
INVALID NUMBER OF WORDS IN MESSAGE
INVALID TEST PATTERN RECEIVED
EC* COMMUNICATIONS UP
EC COMMUNICATIONS DOWN
EC COMMUNICATIONS ENABLED
SELECT MESSAGE RECEIVED FROM EC
INVALID COURSE CHANGE
INVALID SPEED CHANGE
INVALID SPEED TIME CHANGE RATIO
UNABLE TO OPEN FILE
PARAMETER INITIALIZATION COMPLETE
PARAMETER CHANGES COMPLETED
INVALID SET PARAMETER REQUEST
INVALID SHOW PARAMETER REQUEST
INVALID SELECT COMMAND
INVALID FAULT REQUEST
INVALID ENTER COMMAND

NOTES :

1. Alerts are listed in *descending* order of priority.
2. This is the minimal list of alerts specified in [Meyers 88b]. Additional alerts will be defined as required to indicate other erroneous conditions (e.g. time-out detected in the communications link, scheduling deadline missed, buffer overflow).

* External computer

Table 3-4: List of Alerts

3.3.3. System Status Window

The system status window displays the current status of the communications link (down/up) as shown in Figure 2-3. The fixed legend is written once, at program initiation, together with the initial value of the status indicator. When the status of the communications link changes, the appropriate indicator should change within 1000 milliseconds.

3.3.4. Periodic Display Window

The periodic display window displays various numerical quantities relating to the simulated ship motion, in the format shown in Figure 2-3. The fixed legends are written once, at program initiation, together with blanks in the numerical fields. The numerical fields are updated at least once every 1000 milliseconds while the simulation is active (see Chapter 5).

3.4. Disk File Interface (INS Operator Command Scripting)

Command script input is controlled as described in Table 3-3 by the command:

USE FILE <name>

When the operator types a USE FILE command followed by a *file name*, the specified disk file is opened (if possible) and executed. A full path name is not necessary since the system expects the file to be resident on a default processor and disk. The user must provide an otherwise valid file specification (a previously existing external file, thus no file creation is implied) for the operation to proceed. If successfully opened, data will be repeatedly retrieved from the file and processed as command script syntax strings until an end of file is reached. Unsuccessful disk access will result in a posting of an appropriate alert.

4. Internal Behavior

This chapter describes the aspects of INS simulator program behavior that are internal to the program.

When the motion simulation is active (see Chapter 5), three sets of ship motion calculations are performed at specified frequencies.

4.1. Update Ship Attitude

Every 2.56 milliseconds, do the following, as specified in Appendices 2, 3, and 4 of [Meyers 88b]:

- Calculate (simulated) roll and roll rate.
- Calculate (simulated) pitch and pitch rate.
- Calculate (simulated) yaw and yaw rate.
- Calculate (simulated) heading and heading rate.

4.2. Update Ship Velocity

Every 40.96 milliseconds, do the following, as specified in Appendices 5, 6, 7 and 8 of [Meyers 88b]:

- Update the commanded course if a course change is underway.
- Update the commanded speed if a speed change is underway.
- Calculate surge, heave, and sway.
- Calculate velocity of the ship's center of gravity (CG) with respect to the water.
- Calculate true velocity of the ship's center of gravity.
- Calculate motion at the position of the INS within the ship (attitude and velocity).
- Update the cumulative velocity integrals.

4.3. Update Ship Position

Every 1300 milliseconds, do the following, as specified in Appendix 9 of [Meyers 88b]:

- Update the latitude and longitude of the ship.

5. Initialization, Control, and Termination

This chapter describes the process of initializing, controlling, and terminating the INS simulator program.

A typical timeline from program initiation to program termination is shown in Figure 5-1. Note that this timeline represents the ideal case.

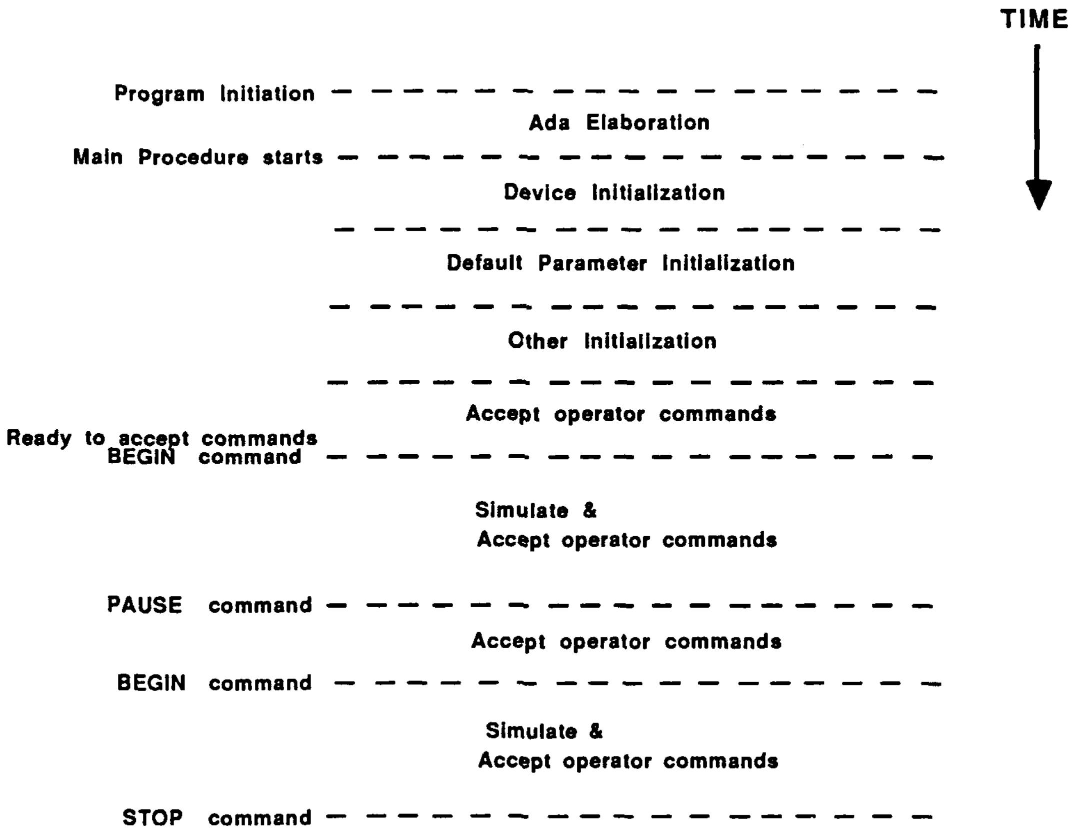

Figure 5-1: Program Time Line

5.1. Program Initialization

The program initialization functions are performed in the order given.

5.1.1. Device Initialization

Some implementation-specific device initializations will need to be performed, but they are not described here. Certain implementation-independent initializations will also be performed, as described in Chapter 3.

5.1.2. Motion Simulator Parameter Initialization

A sea-states table contains seven sets of amplitude and frequency parameters to simulate ship's motion in sea-states 1 through 7. A scenarios table contains fifteen sets of other ship parameters that are required to fully define a simulation. The parameters will be initially set to sea-state 1 and scenario 1.

5.1.3. Other Initialization

The Time of Gyro Reset is set to current wall-clock time.
The state of the communications link is set to DOWN.

5.2. Program Control

The program is now ready to accept operator commands from the keyboard and messages from the external computer system. (Any commands or messages received before this point are ignored). The program remains ready to accept operator commands and EC messages until it is terminated. Wholesale re-initialization of the current parameters may be accomplished by these operator commands:

SELECT SEA-STATE <n>

SELECT SCENARIO <n>

Any of the operator commands listed in Table 3-3 may be now be issued.

The simulation starts when the operator enters a BEGIN command. The simulation is temporarily frozen if the operator enters a PAUSE command; it can be restarted by another BEGIN. The purpose of the PAUSE/BEGIN feature is to assist in debugging and monitoring.)
The program continues until terminated by the operator with a STOP command.

5.3. Program Termination

The INS simulation program is terminated when the operator enters the STOP command, provided that the external computer has already disabled communications. If communications are still enabled, the STOP command is ignored.

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[NAVSEA 82] NAVSEA
Interface Design Specification for the Inertial Navigation Set AN/WSN-5 to External Computer
NAVSEA T9427-AA-IDS-010/WSN-4, August 1982

Appendix A: Timing Constraints

Time (ms)	Type (*)	Item (**)	Reference (***)
2.56	P	Update Ship Attitude	FPS 4.7
	P	Update Ship Heading	FPS 4.9
5.12	T	NRTR "sleep"	IDS 6.3.2.1.b.1
10.24	T	ATTN2 / SOTM Time-Out	IDS 6.2.1.c
10.24	T	SOM / (RTR or NRTR) Time-Out	IDS 6.3.2.1.a
10.24	T	RTR / EOM Time-Out	IDS 6.3.2.2.b
10.24	T	EOM / (ACK or NAK) Time-Out	IDS 6.3.2.1.c
10.24	T	SOTM / (RTR or NRTR) Time-Out	IDS 6.3.2.3.a
40.96	P	Update Ship Speed	FPS 4.6
	P	Update Ship Displacement	FPS 4.8
	P	Update Ship Velocity (& vel integrals)	FPS 4.11
61.44	P	Send Attitude Periodic Message	IDS Table 5-1
983.04	P	Send Navigation Periodic Message	IDS Table 5-1
1000.	P	Update Status Display on Screen	FPS 4.3.1 (2)
1300.	P	Update Ship Position (Lat & Long)	IDS p 4-11

KEY

(*) Type of Timing Requirement
- P Periodic
- T Time-Out

(**) Message EF Codes
- ATTN2 Initialization
- SOTM Start of test message
- SOM Start of message
- EOM End of message
- RTR Ready to receive
- NRTR Not ready to receive
- ACK Acknowledge (i.e., valid message received)
- NAK Not Acknowledge (i.e., invalid message received)

(***) Specification Documents
- IDS Interface Design Specification, AN/WSN-5 to External Computer
- FPS Functional and Performance Specification for INS Simulator

Table A-1: INS Simulator Program: Timing Constraints

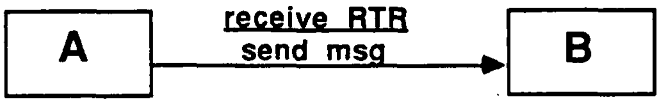
Appendix B: Communications Link Statecharts

This appendix contains a set of statecharts [Harel 86] that describes the behavior of the communications link from the perspective of the INS. This behavior is presented textually in Chapter 6 of [NAVSEA 82]. The goal here is to formalize and clarify.

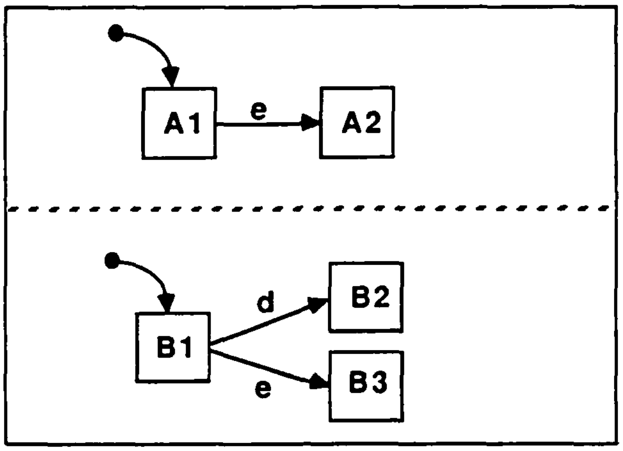
Statecharts incorporate extensions to traditional state transition diagrams that allow for the representation of concurrent states and nested states. The first section below summarizes statechart graphical syntax. The following sections exhibit statecharts with accompanying narrative.

B.a. Summary of Statechart Syntax

1. **States** are represented as boxes. Boxes may be nested, allowing one to view states at varying levels of abstraction.
2. **Transitions** are represented by arrows emanating from a box. Arrows emanating from an outer box represent a transition from any box which it encapsulates. Transitions from several sources may converge on a dot, which also has exiting transitions. This provides an economical mechanism for applying additional conditions and actions to all transitions that converge on the dot.
3. **Events** cause state transitions to take place. They are denoted as labels of a transition.
4. **Actions** may be associated with an event. When actions are present, they appear below a line in the label, where the triggering event appears above the line. An ampersand (&) is a separator between multiple actions.



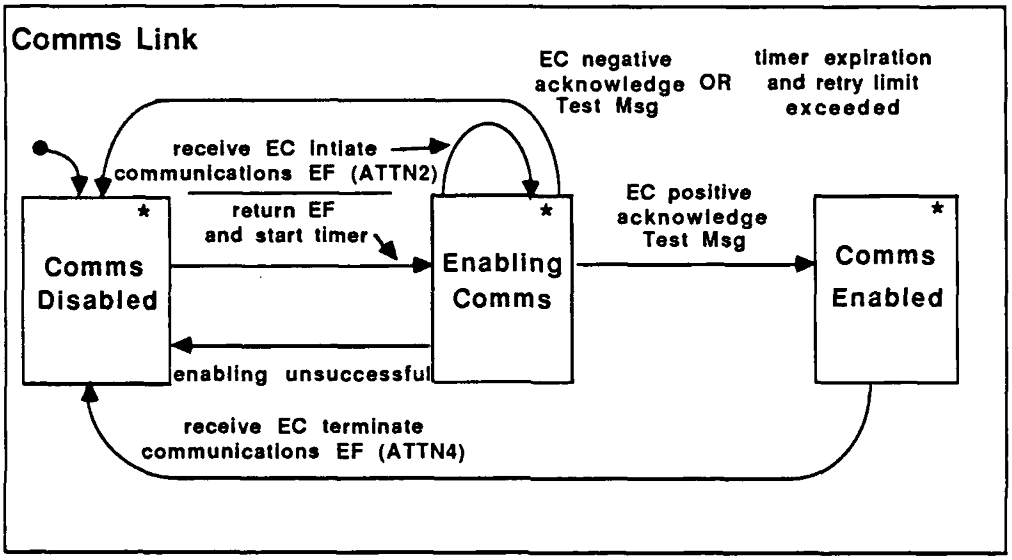
5. **Concurrent states** are represented as two boxes with a common side that is a dotted line.
6. **Initial states** entered when entering a set of encapsulated states are indicated by an arrow with a dot at its tail. In the example below, states ***A1*** and ***B1*** are the initial states that are entered simultaneously, and event ***e*** causes a transition to states ***A2*** and ***B3.***



7. **Conditions** are denoted by text in parentheses. State transitions can be triggered by a true condition.
8. **History** is shown by an arrow that points to an encircled *H*; the *H* indicates that the transition should be made to the most recently exited state.
9. **Expansion** is shown by boxes with an asterisk in the upper right corner; these represent states that have internal detail which is presented in a subsequent statechart.

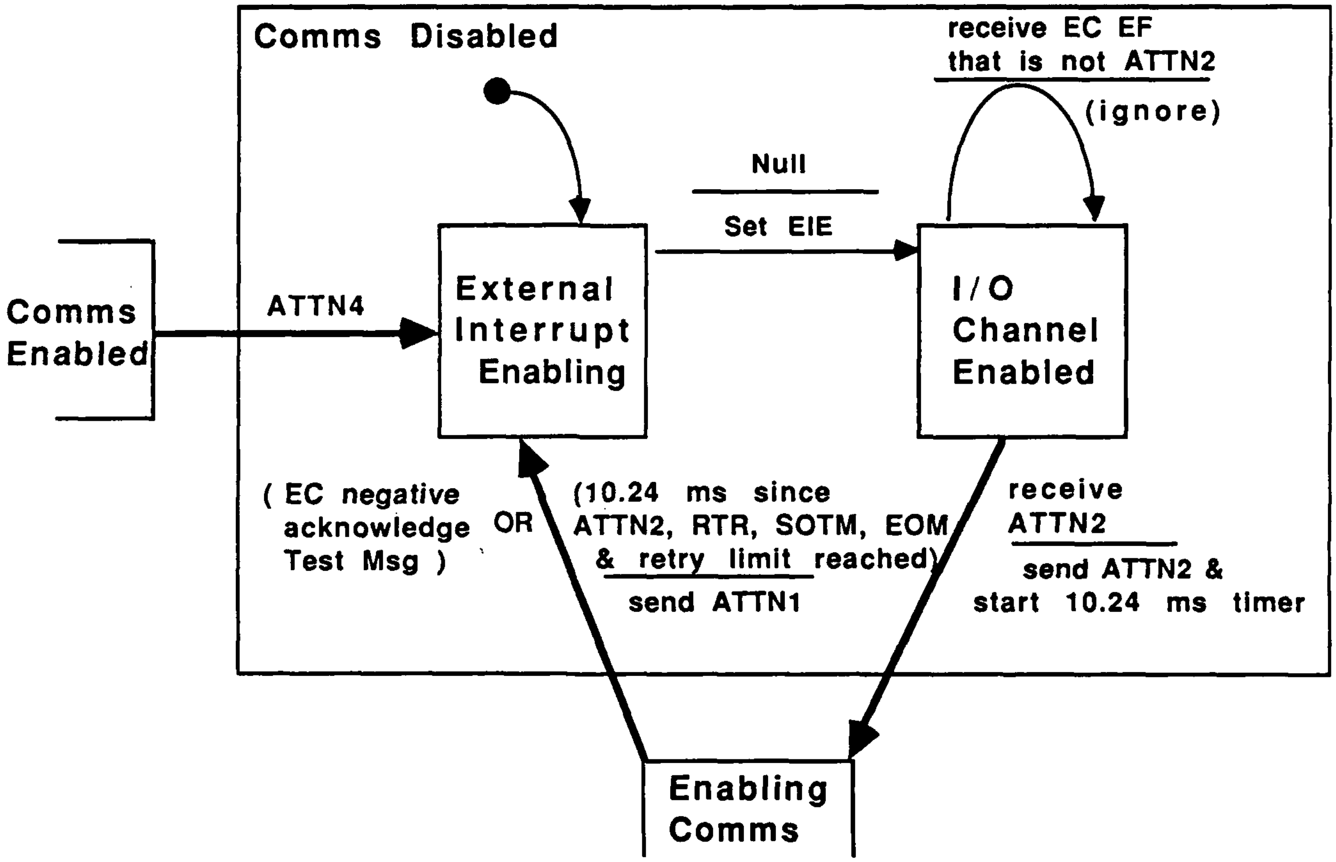
B.b. Master Communications Link Statechart

This chart is the highest level statechart of the INS communications link. It shows the three major states of the communications link: disabled, enabling, and enabled. Receiving an ATTN2 from the external computer precipitates several actions and causes transition to the enabling state. Success in the enabling state results in a transition to the enabled state, and failure to enable results in a transition back to disabled. Note that receiving an ATTN2 and ATTN4 will precipitate the indicated transition from any substate hidden inside the indicated states. Also note that the asterisks in the upper right corner of the boxes indicate that subsequent statecharts exist to show the detail that is hidden at the current level.



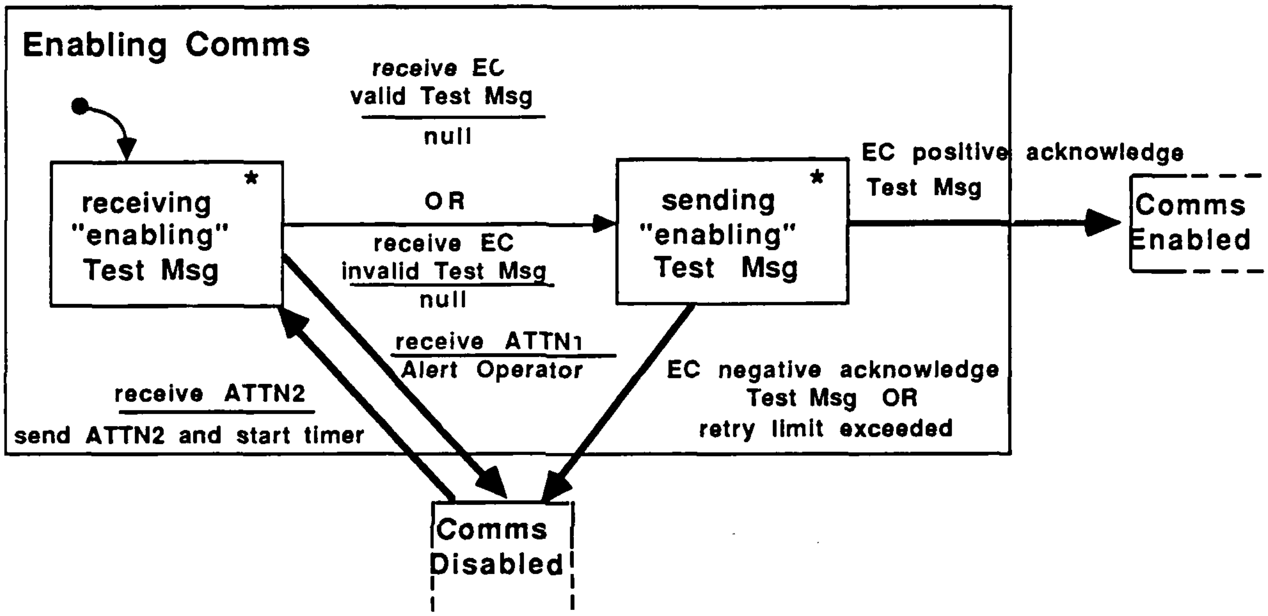
B.c. Communications Disabled Statechart

This statechart is an expansion of the disabled communications state of the higher level. The disabled protocol consists of setting the external interrupt enable (interpreted by the EC as an External Function Request, or EFR), thus triggering an ATTN2 (Enable Communications EF) from the EC and a responding ATTN2 by the INS.



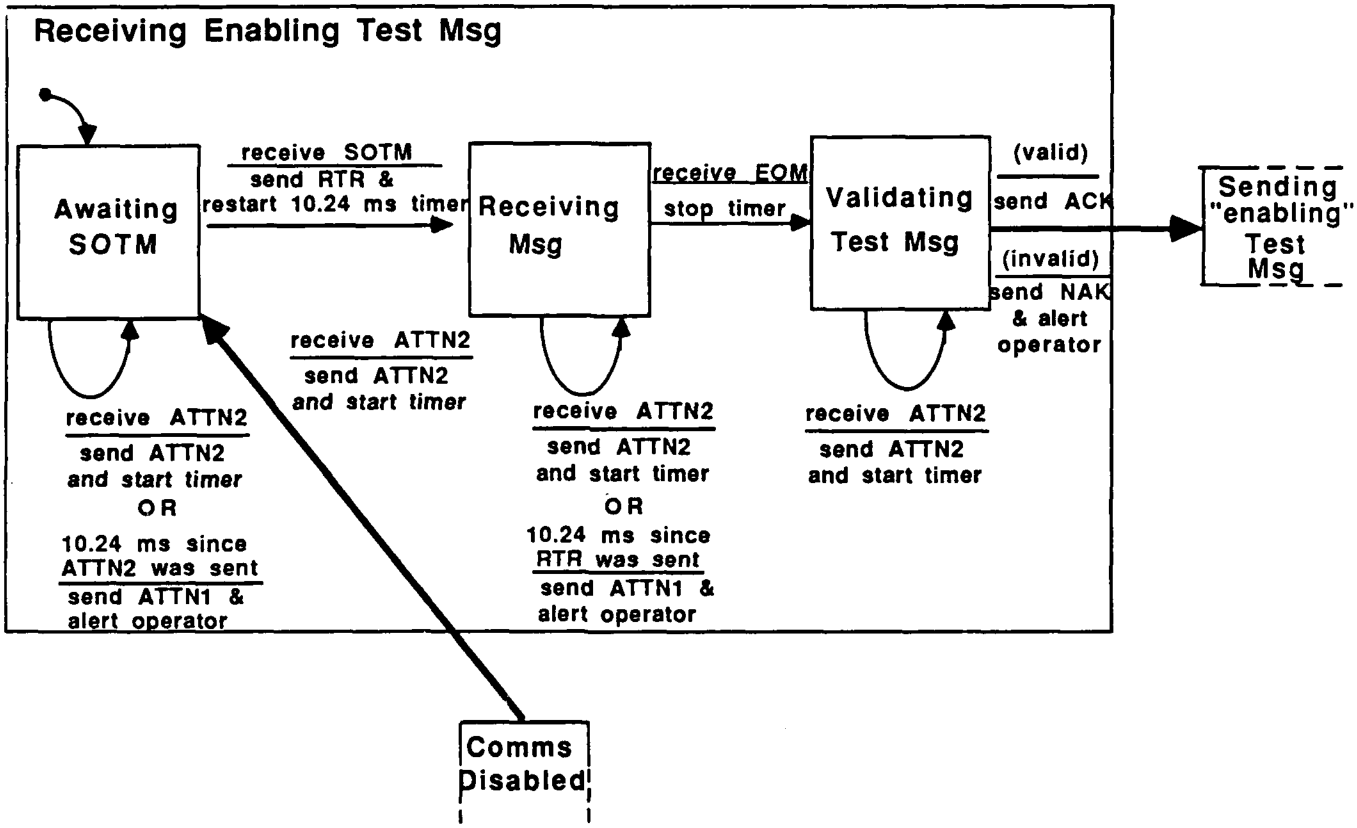
B.d. Enabling Communications Statechart

This statechart is an expansion of the enabling communications state of the higher level. The enabling protocol consists of receiving and sending a test message. Note the use of partial boxes to indicate a state at a higher level.



B.e. Receiving Enabling Test Message Statechart

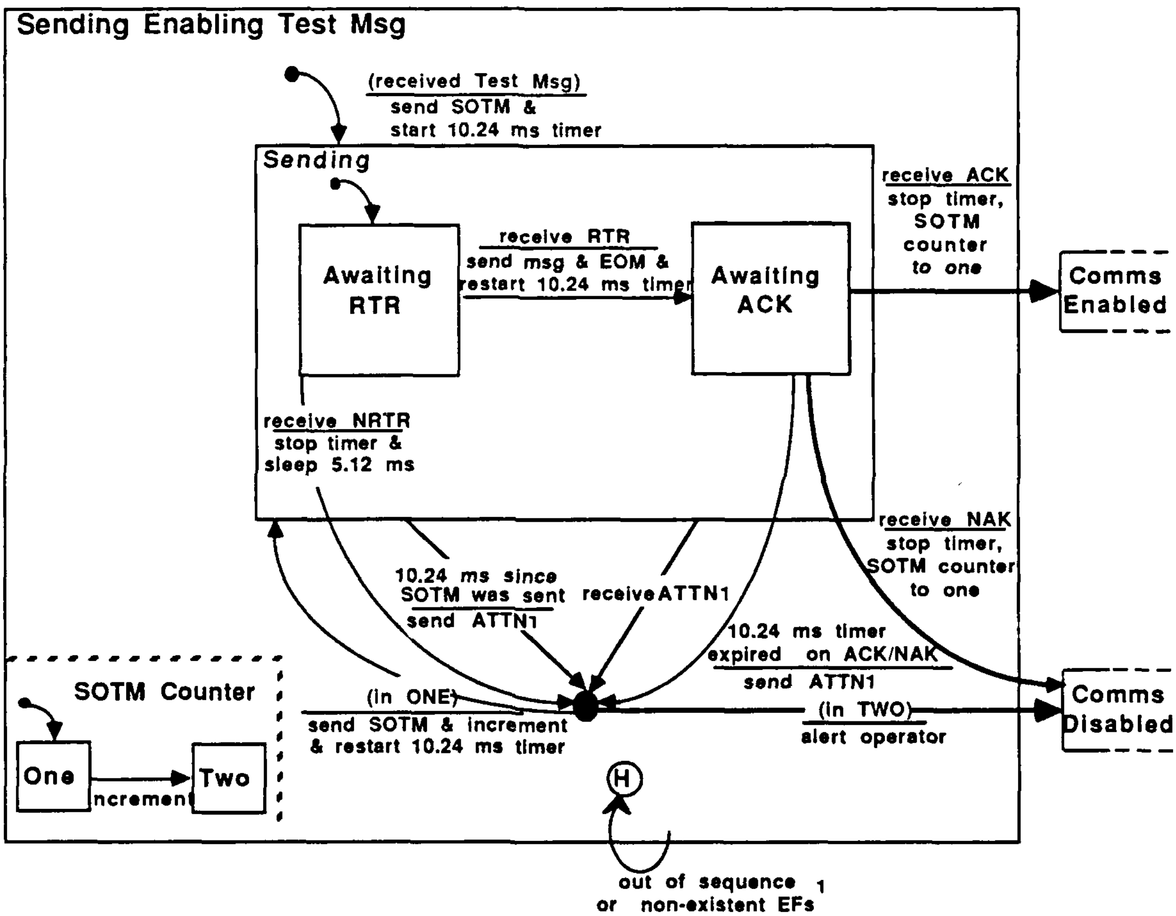
This statechart exhibits the detai!s of receiving a test message during the enabling process. Note that time-outs resul* in a transition back to the disabled state. Also, receiving a NAK when validating the test message results in a transition to the disabled state. Out of sequence or nonexistent EFs are ignored as indicated by the transition to the encircled **H**, with ATTN2 being the exception.



[1] except ATTN2see Comms Link statecharts

B.f. Sending Enabling Test Message Statechart

This statechart exhibits the details of sending a test message during the enabling process. Note that the starting transition in this statechart is labeled with an event that also appears on a higher level statechart (see Section B.d). The actions associated with this event are considered unnecessary detail at the higher level and thus are represented at this level. Also note the use of concurrent states to remember the number of attempts that have been made to send the message.

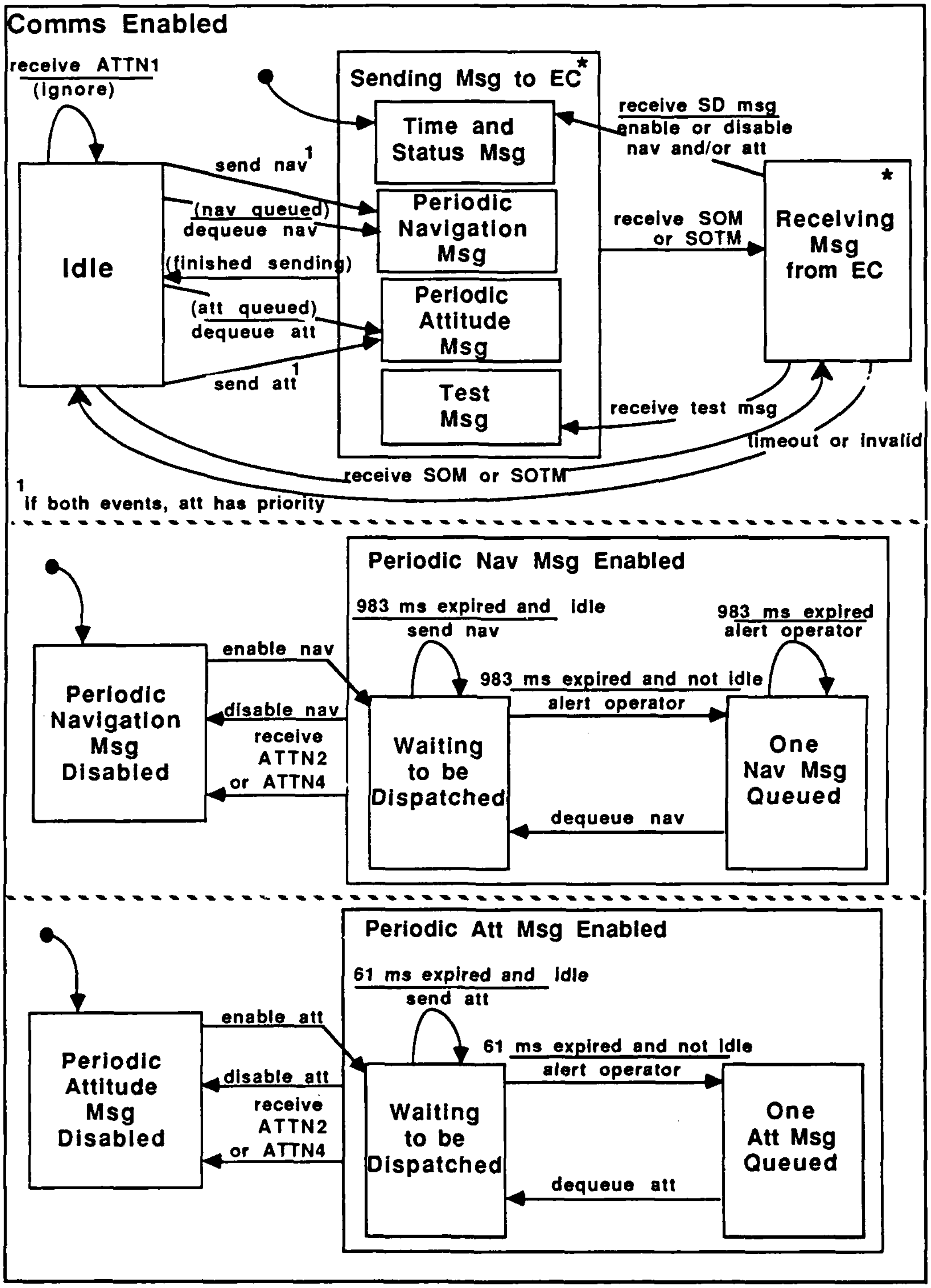


1 except ATTN2: see higher level statecharts

B.g. Communications Enabled Statechart

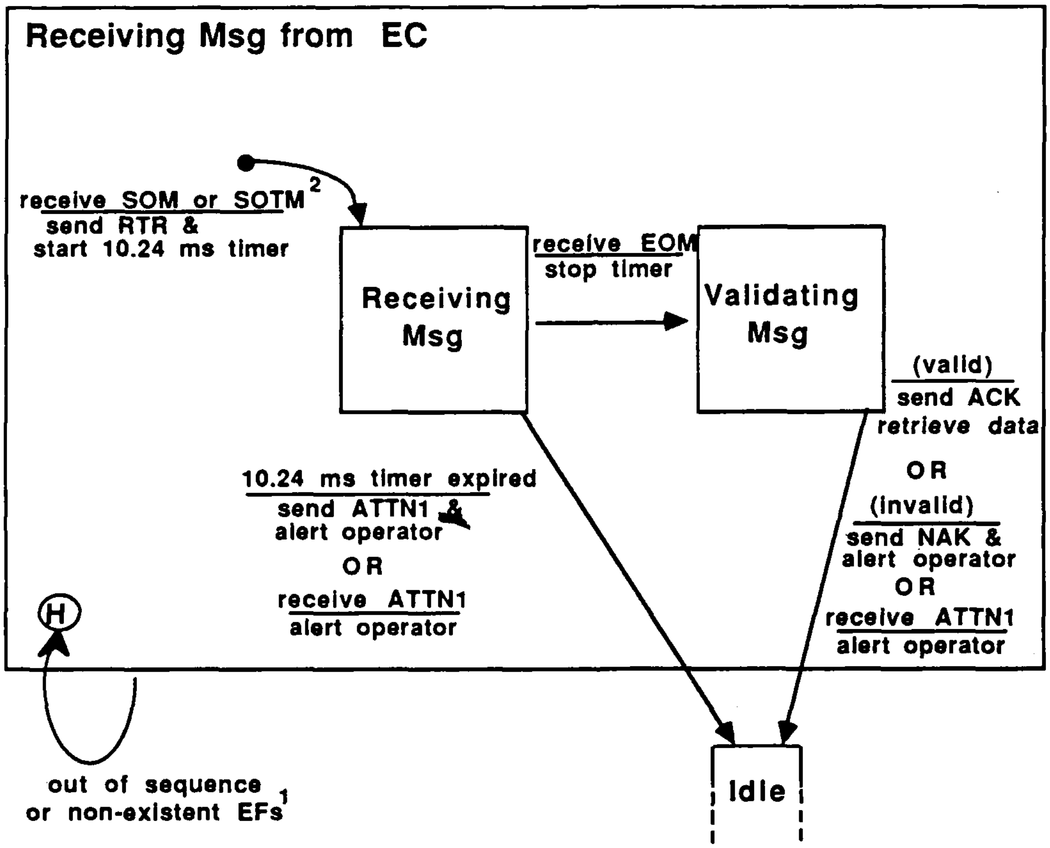
The statechart on the following page presents the details of the communications enabled state as a set of three concurrent states. Upon entering the communications enabled state, the INS sends the time and status message; the sending of the two periodic messages is in a disabled state.

The state, sending message to EC, has four substates, one for each type of message. The detailed statechart for sending each of these messages is common and is exhibited in a later statechart labeled *Sending message to EC* (see Section B.i). Note that if the INS is in the middle of sending a message and either an SOM or SOTM arrive, the original message is aborted and the protocol for receiving a message is enforced. Also notice the interactions between several concurrent states. For example, when the select data (SD) message arrives and requests that the INS send periodic navigation data, the associated action is *enable nav.* This action is also an event which triggers the transition to the state of waiting to be dispatched.


Comms Enabled
receive ATTN1
(ignore)
Sending Msg to EC *
Time and Status Msg
Periodic Navigation Msg
Periodic Attitude Msg
Test Msg
Idle
send nav 1
(nav queued)
dequeue nav
(finished sending)
(att queued)
dequeue att
send att 1
receive SD msg
enable or disable nav and/or att
receive SOM or SOTM
Receiving Msg from EC *
receive test msg
timeout or invalid
receive SOM or SOTM
1 if both events, att has priority
Periodic Nav Msg Enabled
983 ms expired and idle
send nav
983 ms expired
alert operator
983 ms expired and not idle
alert operator
Periodic Navigation Msg Disabled
enable nav
disable nav
receive ATTN2 or ATTN4
Waiting to be Dispatched
One Nav Msg Queued
dequeue nav
Periodic Att Msg Enabled
61 ms expired and idle
send att
61 ms expired and not idle
alert operator
Periodic Attitude Msg Disabled
enable att
disable att
receive ATTN2 or ATTN4
Waiting to be Dispatched
One Att Msg Queued
dequeue att

B.h. Receiving Message from External Computer Statechart

This statechart represents the details for receiving any message when communications is in the enabled state. It is similar to the statechart that shows receiving a test message during enabling (*refer to the statechart in Section B.e*).

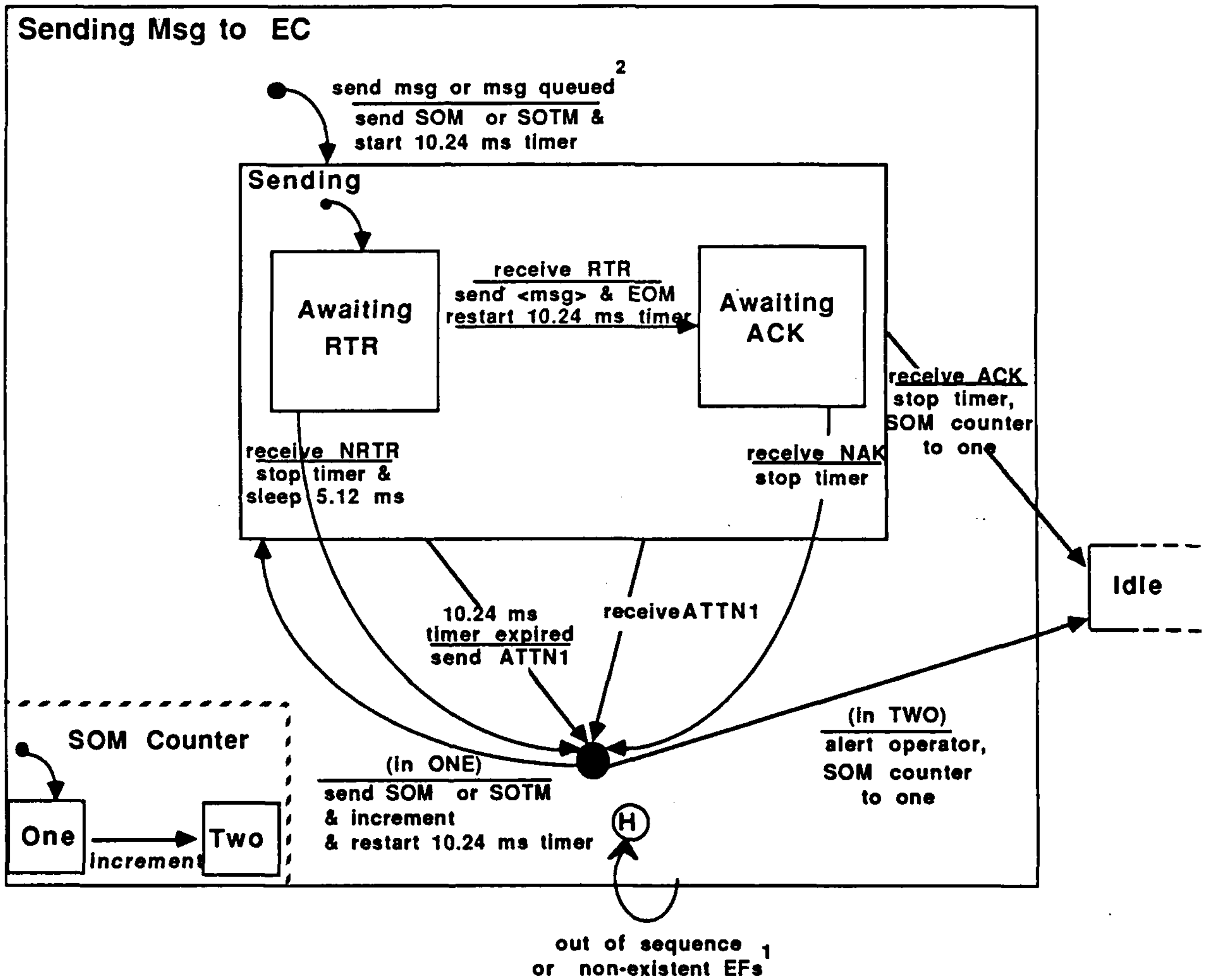


[1] except SOM, SOTM, ATTN2 and ATTN4; see higher level statecharts

[2] this event is also shown on previous statechart

B.i. Sending Message to External Computer Statechart

This statechart represents the details for sending any message when communications is in the enabled state. It is very similar to the statechart that shows sending a test message during enabling (refer to the statechart in Section B.f).



1 except SOM or SOTM and ATTN2 & ATTN4: see higher level statecharts

2 the Comms Enabled statechart also represents this event

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